

Audio reproduction apparatus, feedback system and method

The invention relates to an audio reproduction apparatus comprising:

- input means for inputting an input audio signal;
- an output for outputting an output audio signal derived from the input audio signal;
- 5 - a cost input for inputting a mathematical cost derived from a measurement, which measurement is user-influenceable; and
- a conditioning unit, capable of delivering the output audio signal in dependence of the mathematical cost.

The invention also relates to an audio feedback system comprising:

- 10 - an audio source;
- a measurement device arranged to deliver a measurement which is user-influenceable;
- a mathematical cost calculation unit, arranged to derive a mathematical cost from the measurement;
- 15 - a sound production device; and
- a conditioning unit arranged to receive an input audio signal from the audio source, to receive the mathematical cost, and to deliver to the sound production device an output audio signal derived from the input audio signal, in dependence of the mathematical cost.

- 20 The invention also relates to a method of deriving an output audio signal from an input audio signal in dependence of a mathematical cost derived from a measurement which is user-influenceable.

The invention also relates to a computer program for execution by a processor, describing above mentioned method.

- 25 The invention also relates to a data carrier storing the computer program.

An embodiment of such an audio reproduction apparatus is known from US-A-4,788,983. The known apparatus is designed for use by a person performing a sports

activity, who wants to listen to music. The known apparatus contains a conditioning unit capable of transmitting an input audio signal from a walkman as an output audio signal to headphones. The conditioning unit also receives a mathematical cost signal from a heart rate measurement device. A user specifies according to e.g. his age or sex a safe window of heart rate which he wants to use during his training. If his heart rate is too low, he is clearly not getting enough exercise. On the other hand, if his heart rate is too high, his exercise might be unhealthy. The conditioning unit transmits the input audio signal only if the measured heart rate is within the desired window, and otherwise no sound is sent to the headphones.

It is a disadvantage of the known apparatus that such a crude regulation of the output audio signal is not user friendly. E.g. if the window is narrow, it is difficult for a user to judge whether he has lost his music because he is running too slow or too fast.

It is an object of the invention to provide an audio reproduction apparatus of the kind described in the opening paragraph, which is relatively versatile as far as the regulation of the output signal is concerned.

The object is realized in that the conditioning unit comprises an audio processing means arranged to process the input audio signal to derive the output audio signal with a reproduction quality in dependence of the mathematical cost. The conditioning unit of the known audio reproduction apparatus contains elements which only implement a switch function. In case the heart rate is outside the window, no signal is sent to the headphones. This is not very desirable. If the user is training just a little too soft, he will hear absolutely no sound. Rather than to be motivating to start running harder again, this can be very demotivating for certain users. It is desirable that there is a gradual change, so that the user can underachieve during a certain period and still have music. Furthermore heart rate measurements are not always reliable, e.g. if a signal of a nearby second user is picked up. The user is then punished for something out of his control. The audio reproduction apparatus according to the present invention is arranged to offer the user many more versatile strategies of responding to his sports activity, embodied as strategies of calculating the mathematical cost. The apparatus according to the invention is also arranged to provide more versatile output audio presentation strategies. Instead of just switching off the output audio signal, the apparatus of the invention offers options of changing the reproduction quality of the output audio signal. This is a physical measurable and determinable correlate to the perceptible psycho-acoustical quality of the sound. E.g., the audio reproduction apparatus may be able to

gradually lower the sound amplitude, leading to less intelligible music. Alternatively, if stereo is present an underachieving user can be punished in that the audio reproduction apparatus delivers mono instead of stereo, in which case the number of independent output signals is a reproduction quality measure of the perceived psycho-acoustical quality.

5 In an embodiment, the reproduction quality comprises a three-dimensional position of a virtual sound source, the audio processing means being able to simulate the virtual sound source by means of the output audio signal. Of the set of all audio-processing functions which can be applied to obtain some psycho-acoustical quality, some realize the audio positioning of a virtual sound source in three-dimensional space around the head of a user. This is especially interesting for the user traveling a distance -real or virtual- such as a jogger or somebody on a bicycle hometrainer. If he instructs the apparatus that he should run at a certain speed, he should be at a certain position -real or virtual- at a certain time. The audio reproduction apparatus can position the virtual sound source by sending an appropriate audio signal to a left and a right loudspeaker of the headphones, the virtual sound source being e.g. two virtual loudspeakers at a distance of 1 meters in front of the user. If the user runs too slow the virtual loudspeakers move away from him, and this can be simulated if desired by making the sound emerging from the virtual loudspeakers become ever less audible. The user can catch up with the loudspeakers by running faster. By adding synthetic reverberations other three-dimensional audio position quality measurements can be influenced, such as the illusion of a wall in front of the user.

In a modification of the embodiment, the audio processing means comprise a filter arranged to simulate the position of virtual sound source by deriving the output audio signal by filtering the input audio signal with a user dependent head related transfer function (HRTF). By means of an HRTF a sound source such as a virtual loudspeaker can be accurately positioned. The input audio signal for the left resp. the right headphone loudspeaker is filtered by a respective HRTF, simulating the path through a virtual room of sound from an actual loudspeaker at a position in the room to the respective ear of the user.

In another modification of the embodiment or a further variation on the foregoing modification, the audio processing means comprise an audio processing unit arranged to simulate the position of the virtual sound source by changing a property of the output audio signal selected from signal amplitude and added reverberation. Both properties are simple signal processing functions to realize the illusion of sound with a specific three-dimensional audio position quality.

The audio processing means can also be arranged to derive a second output audio signal, together with the output audio signal constituting a stereo audio signal, the audio processing means being arranged to derive the stereo audio signal from the input audio signal with a specified stereo quality dependent on the mathematical cost. Signal processing functions influencing the stereo quality are e.g. the following:

- the virtual loudspeakers are moved closer to each other if the user underachieves;
- the audio signals for the left and right virtual loudspeakers are made more similar if the user underachieves; or
- one of the virtual loudspeakers disappears if the user underachieves.

The last option can also be implemented as a -gradual or brusque- switch between multichannel surround such as Dolby 5.1 and 2 channel stereo. Varying the stereo quality is advantageous given the widespread presence of stereo sound.

It is advantageous if the reproduction quality comprises a specification of the distribution of frequencies of the output audio signal. By changing the frequency content of the output audio signal, the audio processing means can simulate other effects. E.g. an underachiever is punished by removing the bass of the audio signal. The three-dimensional position of a virtual sound source can be influenced by such an audio processing function too. E.g. the audio processing means may be arranged to remove high frequencies as if the sound has to travel a long way through a thick fog, or resides at a depth in a virtual wall.

It is also advantageous if the audio reproduction apparatus comprises a first quality calculation unit for determining the reproduction quality for use in the subsequent derivation of the output audio signal by the audio processing means. The reproduction quality is a property of the output audio signal. The audio reproduction apparatus could measure it on the output audio signal, but then the input audio signal first has to be processed by an a priori unknown processing algorithm. A correlate reproduction quality can be determined by the first quality calculation unit and send to the audio processing means which applies a corresponding processing function. E.g. changing the angle of two virtual loudspeakers has an influence on the stereo quality, and it is in general not necessary to specify what numerical stereo quality a user experiences. If more accuracy is desired, a specific angle function can be stored in a memory, e.g. based upon user panel tests. It is also possible that the user specifies a relation between e.g. his running speed and the angle himself, or chooses between a number of prestored functions, some of which change the angle slowly and other quickly.

Alternatively or additionally it is advantageous if the audio reproduction apparatus comprises quality measuring means for measuring an output quality measure of the output audio signal, and comprises parameter value calculation means for calculating a parameter value, for use in the subsequent derivation of the output audio signal by the audio processing means. If the quality of the output signal is measured, it can be fed back for changing the processing on the input audio signal for future times. Such a feedback control loop obtains the desired reproduction quality after some tuning time. The parameter value calculation means can take an incompatibility between the result of the reproduction quality measurement and the desired quality measurement into account. The parameter value is changed accordingly, steering the processing function until it obtains the desired audio output signal reproduction quality.

In another embodiment a mathematical cost calculation unit is comprised which is arranged to derive the mathematical cost from the measurement receivable from a measurement device. A mathematical cost can be derived from any kind of apparatus, e.g. a random generator if the audio reproduction apparatus is used in a competitive game. Typically the mathematical cost may be determined on the basis of a measurement which the user can influence, such as his running speed, heart rate, etc. A measurement device could send the mathematical cost directly to the apparatus, e.g. as a coded number. Typically however the audio reproduction apparatus may contain the new functionality, so that it can be used with an off-the-shelf measurement device.

In a modification of the previous embodiment, the mathematical cost calculation unit is arranged to derive the mathematical cost based on a difference between the measurement and a chosen value. E.g., the user sets this chosen value being his desired running speed as 10 km/h, or his desired heart rate as 180 bpm. The quality is then e.g. determined as the actual running speed minus 10 km/h. The faster he runs, the more the reproduction quality changes. Or in an alternative version, if he runs a little harder nothing happens, and if he runs a lot harder the audio processing means are arranged so that the reproduction quality starts changing gradually depending on the amount of time he is running harder than the chosen value.

In an alternative modification of the previous embodiment or in addition to the previous modification, the mathematical cost calculation unit is arranged to derive the mathematical cost from a biometric measurement. Engineering quality audio systems and biometric measurements are totally unrelated fields of technology. Apparently, nobody sees a need of combining them. Biometric measurement systems are usually designed by engineers

who work in close cooperation with physicians, and priorities in this field are exactness and robustness of the measurements and safety. The quality of audio reproduction is more an artistic matter of taste. This has led to the fact that biometric measurements are usually displayed on numeric displays. An exception is the beeps of a medical monitor, but the audio
5 functionality of such monitors is designed for simplicity rather than artistic reproduction quality. There is a need for user-friendly feedback of biometric data while training, since a user does not like to watch a display continuously while training. Sound however when present automatically enters the user's ear.

The audio feedback system is characterized in that the conditioning unit
10 comprises an audio processing means arranged to process the input audio signal for the derivation of the output audio signal with a reproduction quality in dependence of the mathematical cost. It is advantageous to produce the system as a whole since then all components can be realized as being optimally tuned to each other.

The method of deriving an output audio signal from the input audio signal in
15 dependence of the mathematical cost derived from a measurement which is user-influenceable is characterized in that the output signal is derived with a specified reproduction quality dependent on the mathematical cost.

20 These and other aspects of the audio reproduction apparatus, the method, the audio feedback system, the computer program and the data carrier according to the invention will be apparent from and elucidated with reference to the implementations and embodiments described hereinafter, and with reference to the accompanying drawings, which serve merely as non limiting illustrations.

25 In the drawings :

Fig. 1 schematically shows an application of the audio reproduction apparatus;

Fig. 2 schematically shows an embodiment of the audio reproduction
apparatus;

Fig. 3 schematically shows an embodiment of the audio processing means of
30 the audio reproduction apparatus;

Fig. 4 schematically shows an embodiment of the audio feedback system;

Fig. 5 schematically shows an embodiment of the data carrier;

Fig. 6a and b schematically show a respective example of a mathematical cost
function;

Fig. 7 schematically shows an example specification of a position quality as a function of mathematical cost; and

Fig. 8 schematically shows an example of a frequency spectrum of an output audio signal output by the audio reproduction apparatus.

5 In these Figures elements drawn dashed are virtual in Fig. 1, and optional in the other Figures, depending on the desired embodiment. Not all elements present in the illustrative embodiment of the audio processing means in Fig. 3 need be present in an alternative embodiment.

10 Fig. 1 shows a user 100 of the audio reproduction apparatus 200 according to the invention, who is jogging. He could e.g. also be rowing on an indoors rowing machine. While doing his sports activity he is listening to music coming as an output audio signal - see Fig. 2- from the audio reproduction apparatus 200, being e.g. a portable audio player such as an MP3 player, and reproduced by the left and right headphone loudspeaker 114 and 115
15 of a sound production device 102, typically being headphones. The reproduction quality R of the music is changed by the audio reproduction apparatus 200 in dependence of the sports performance of the user 100, e.g. varying between Dolby 5.1 and mono without bass frequencies. E.g. if he runs too slow, he is penalized with music of bad reproduction quality R. His performance can be measured by at least one of various sensors. E.g. a pace meter 108
20 connected to his sports shoe or another measurement device like a heart rate meter 106 delivers a measurement signal m. For the heart rate meter 106 this measurement can be e.g. a PQRST complex of an electrocardiogram, a time sequence of pulses, or a number representing the heart rate. The audio reproduction apparatus 200 converts this measurement m to a reproduction quality R.
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In a simple variant of the audio reproduction apparatus 200, the audio reproduction strategy is fixed, and the user 100 can only specify the way in which the measurement is transformed into a mathematical cost c. Note that for clarity reasons the examples are described for an embodiment in which all the mathematical transformations are
30 realized as software algorithms running on a processor, but dedicated hardware circuitry could also be used. E.g. the user 100 can specify an interval iv in which his heart rate should lie such as [LL, LU] in Fig. 6a. A mathematical cost function 602 is shown in a coordinate system 600 with on the x-axis the heart rate measurement m minus a chosen value d and on the y-axis the mathematical cost c. This chosen value d is set by the user as the target heart

rate for his training, e.g. 180 bpm. The interval [LL, LU] can be symmetrical or asymmetrical around the chosen value d. The mathematical cost function can be fixed in the hardware of the audio reproduction apparatus 200 of Fig. 2, or the user can specify by means of user interface means 311 of Fig. 3 how the mathematical cost changes with m-d. E.g. as in Fig. 6a up to the marker values ML and MU the mathematical cost changes linearly with a small slope, while between the marker values and the limits of the interval iv the mathematical cost slopes more steeply, and outside the interval iv the mathematical cost increases very steeply. In an alternative mathematical cost function 606 specification shown in Fig. 6b, the mathematical cost is non-zero and linearly changing only outside the training interval iv. E.g. in Fig. 6b the user 100 has designed a cost function with negative values if he is running too slow. A negative cost can then during reproduction easily be mapped e.g. as a negative angle α of a virtual sound source, and a positive cost corresponding to speeds which are too high as a positive angle α . In this way both cases can be easily discriminated. The user has freedom in designing the cost function by choosing e.g. training interval limits, quickness of change of the cost—which can be translated into quickness of change of audio reproduction quality R-, whether only measurements below the chosen value d are leading to nonzero cost, etc.

The user interface means 311 are e.g. software running on a processor, which requests the user to type numerical values of marker values and slopes, or which allows the user to draw the mathematical cost function 602 graphically. The fixed audio reproduction strategy is e.g. the one illustrated in Fig. 7. Here the reproduction quality R is embodied as what is called in the rest of the text a position reproduction quality P, which is any specification of a physical parameter of the output audio signal o resulting in the perception that the output audio signal comes from a position of a virtual sound source. E.g. the virtual sound source can be perceived close to a user's head or far away, or in Fig. 7 it is an angle α of a virtual sound source around a user's head. If the user 100 is running with the desired target speed, the mathematical cost c is zero and the angle α is also zero degrees, i.e. the virtual sound source is right in front of the user 100. If the runner runs too slow or fast, the mathematical cost c with a specification like in Fig. 6b decreases resp. increases, and the virtual sound source shifts to the left resp. right side of the user 100. The sound source can stay behind the user until the user 100 runs with the desired speed of the chosen value d again or runs with the desired speed again for a certain amount of time. Alternatively, the sound source can also start behind the user 100, being an annoying motivation to run harder.

In more advanced variants of the audio reproduction apparatus 200, the user 100 can also specify the strategy for changing the reproduction quality as a function of the

mathematical cost c . He can program a first quality calculation unit 330 in Fig. 3 which outputs e.g. as a stereo quality S an angle 160 between a first virtual sound source 152 and a second virtual sound source 154 generated by the output audio signal o and a second output audio signal o_2 , as a linear function of the mathematical cost c . Or he can select an

5 alternative or additional audio processing function, which e.g. adds an amount of reverberation as a function of the mathematical cost c to simulate a distance of a virtual loudspeaker in a virtual room.

Another example application of the audio reproduction apparatus 200 is the prevention of repetitive strain injury (RSI) or inactivity. In this case user 100 sits e.g. in front

10 of a personal computer (PC) or on a couch in front of a television (TV). The sound production device 102 is e.g. a loudspeaker connected to the PC or television. The chosen value d is the amount of time the user 100 wants to work or watch TV before taking a break. The mathematical cost c is e.g. determined by the amount of time t elapsed since a starting time t_0 minus the chosen value d , being the allowable time to work or watch TV

15 continuously:

$$c = (t - t_0) - d \text{ if } t - t_0 > d ;$$

$$c = 0 \text{ if } t - t_0 < d \quad [1]$$

With two loudspeakers of a TV or PC, a virtual sound source position can be simulated.

20 Fig. 2 schematically shows an embodiment of the audio reproduction apparatus 200 in its basic form. An input audio signal i comes in via an input means 204 from e.g. a portable MP3 player or the sound card of a PC. The input audio signal i can come from outside or inside the audio reproduction apparatus 200. In the latter case the audio reproduction apparatus 200 may comprise e.g. a CD player unit or any other internal audio

25 source 201. The input audio signal i can be mono or multichannel audio. There is also a cost input 208 for receiving a mathematical cost c from a mathematical cost calculation unit 210, which is arranged to derive the mathematical cost from a measurement made by a measurement device 212. The mathematical cost calculation unit 210 can be incorporated in the audio reproduction apparatus 200 or can be separate, e.g. in the measurement device 212.

30 The measurement device 212 is typically not incorporated in the audio reproduction apparatus 200, although it could be, in case it is e.g. a clock. The audio reproduction apparatus 200 contains a conditioning unit 202, which contains an audio processing means 216 arranged to process the input audio signal i to derive the output audio signal o with a reproduction quality R in dependence of the mathematical cost c . The output audio signal o

goes to an output 206, to which a loudspeaker 214 can be connected. The audio processing means 216 can just perform a single parametric function leading to an output audio signal o of variable reproduction quality and hence perceptible psycho-acoustical quality, or multiple audio processing algorithms can be applied alternatively or simultaneously as in Fig. 3.

5 Fig. 3 schematically shows an audio processing means 316, being an embodiment of the audio processing means 216 of the audio reproduction apparatus 200. In the audio processing means 316 a number of processing units are shown purely for explaining various features of the audio reproduction apparatus 200, and it should be clear that other combinations are possible. The audio processing means 316 is arranged to supply
10 an output audio signal o to a first loudspeaker 314 and if required a second output audio signal o2 to a second loudspeaker 315.

For many audio processing algorithms, the reproduction quality R can be set in advance, and a subsequent audio processing is chosen depending on the reproduction quality R. E.g. the reproduction quality R can be a parameter of an audio processing algorithm, as in
15 the case where the amplitude of the output audio signal is set. This can be realized with a variable gain amplifier. In other cases, user panel tests or the preferences of the actual user of the audio reproduction apparatus 200 can be used to select an appropriate processing algorithm, e.g. the first, second or third processing algorithm, 320, 322 resp. 324. In the example embodiment of Fig. 3, a third mathematical cost c3 from a second measurement
20 device 352 goes to an algorithm selector 326, which e.g. contains a table of intervals. If the third mathematical cost c3 falls within a first interval, the first processing algorithm 320 is selected, etc. Such a configuration makes it possible to switch to entirely different algorithms dependent on the value of the third mathematical cost c3. E.g., the first algorithm may change the angle 160 between two virtual loudspeakers, depending on where in the first interval the
25 third mathematical cost c3 falls. If the third mathematical cost c3 becomes so high that it falls outside the first interval and in a second interval, the second processing algorithm 322 is selected, which e.g. changes the amplitude of the signals from the virtual loudspeakers, or both the angle 160 between them and the signal amplitudes. Another example in which the reproduction quality R is set prior to the processing is the setting of an angular position on a
30 sphere around the user's 100 head of a virtual sound source by means of a head related transfer function HRTF. E.g., when the user 100 wears headphones, the input audio signal i can be simulated to come from a virtual sound source position, by filtering it by means of filter 332 using a specific first HRTF to obtain the output audio signal o for the left headphone loudspeaker 114 and using a specific second HRTF to obtain the second output

audio signal o2 for the right headphone loudspeaker 115. Both HRTFs are dependent on the required position of the virtual sound source- e.g. specified as two angles on a unit sphere- and can be fetched from a memory 334 containing HRTFs for a number of different positions. A first quality calculation unit 330 determines the reproduction quality R needed for further audio processing. E.g. in the above described case the first quality calculation unit 330 calculates an angle α of the virtual sound source, used for fetching the HRTFs, as a linear function of a first mathematical cost c1. The first mathematical cost c1 is derived from a measurement device 312 by a mathematical cost calculation unit 310, which e.g. evaluates a function like the one in Fig. 6a. Details on measuring HRTFs can be found in patent WO 01/49066 and paper "F.L. Wightman and D.J. Kistler: Headphone simulation of free field listening. I: Stimulus synthesis. Journal of the Acoustical Soc. of America 85 no. 2, Feb. 1989, pp. 858-867."

In other cases, the reproduction quality R has to be measured on the output audio signal o itself, e.g. because the relation between the reproduction quality R of the output audio signal o and the particular processing is too complex to formulate or unknown. In this case feedback can be used to select the right processing algorithm or the right parameter for a parametric processing algorithm. Quality measuring means 344 measure an output quality measure M of the output audio signal o. The output quality measure M and a desired reproduction quality R from a second quality calculation unit 340 are fed to a parameter value calculation means 346. From these two parameters, a parameter value pv is calculated for steering subsequent processing by an audio processing unit, which selects a particular processing algorithm or changes a parameter of a parametric algorithm. This can be done by any technique known from control theory. E.g. An update parameter value pv can be calculated as in equation [2]:

$$pv = \delta(M - R) \quad [2]$$

Actually parameter value pv can be any function of M and R, if necessary also taking into account that the output quality measure M is a different function of the desired psycho-acoustical quality than the reproduction quality R.

The required implicit functionality between the output quality measure M and the reproduction quality R derived from the first mathematical cost c1, can be specified by user 100. With user input means 360, e.g. a key board, a touch sensitive panel, or a turning knob and user interface means 311, the user 100 can specify a number of desired measurement values d, which are converted to corresponding first mathematical costs c1 and reproduction qualities R. Instead of inputting desired measurement values d, the user 100 can

also input desired mathematical costs c_s . During this learning stage, for each reproduction quality R a number of processing algorithms with corresponding output quality measures M is scanned. When the output quality measure M corresponding to a psycho-acoustical quality as desired by the user 100 is reached, the user 100 can indicate this to the parameter value calculation means 346 via a learning control connection lc –wired or wireless. The parameter value calculation means 346 can then store the pair reproduction quality R and parameter value p_v , so that during operation, the feedback is no longer needed, but rather that from a reproduction quality R corresponding to a measurement m , the correct parameter value p_v can be sent to an audio processing unit 342. The learning control connection lc can also be used to specify which of the available processing should be used for obtaining an output audio signal o with the desired reproduction quality R , by setting an output selector 370.

Another example of putting user preferences in the audio processing means 316 is illustrated with a second user input means 361. In this example, the user 100 can directly enter a second desired mathematical cost c_s' and a corresponding desired processing algorithm selection na into the algorithm selector 326.

Note that in many cases the exact perceived psycho-acoustical quality, e.g. the exact position of a virtual sound source is not important, but only that the psycho-acoustical quality changes monotonically. This relaxes the requirements on the reproduction strategy. Any mapping of virtual sound source angle to mathematical cost e.g. might already be sufficient.

Many processing algorithms can be designed to create some perceptible psycho-acoustical quality corresponding to a reproduction quality R characterizing a selected algorithm. E.g. a reproduction of bass frequencies can be changed in dependence of the mathematical cost. As shown in Fig. 8, as a particular reproduction quality R or part of a reproduction quality R , a specification SPEC can be calculated reflecting the spectral content of the output audio signal o . One example of the specification SPEC is a frequency below which there is substantially no sound energy present, e.g. a first low frequency FL1 or a second low frequency FL2. E.g. if the user runs at nearly the desired speed, bass frequencies are reproduced all the way down to the first low frequency FL1. However if he runs too slow, he loses the bass frequencies between the first low frequency FL1 and the second low frequency FL2. Another example of the specification SPEC is the percentage of energy in bass range $[FL1, FL2]$ compared to the energy in range $[FL3, FH]$. Any equalization strategy can be employed as a function of the cost c , e.g. the amount of treble may be a function of the cost c .

An interesting algorithm sets the mathematical cost function by means of a three-dimensional bubble 150 around the user's 100 head. If he runs too slow, the distance between the virtual position of his head 158 and a mark point 156 in the bubble increases, which leads to an increased mathematical cost c , and a decreased reproduction quality R . The reproduction quality R can also change in dependence of whether the user 100 is inside the bubble 150 or not, which gives him a training tolerance. The virtual movement of the bubble 150 compared to the running of the user could even keep track of whether the user was waiting for traffic lights, this situation being identified e.g. when he pushes a button. When inside the bubble 150, the sound could e.g. sound as if the user 100 is in a particular room, by selecting HRTFs corresponding to that room, whereas outside the bubble 150, the sound sounds dull.

The distance of a virtual sound source can also be simulated. The audio-processing unit 342 can e.g. simulate the distance of the virtual sound source by changing the amplitude of the output audio signal o and second output audio signal o_2 . Or reverberation can be added. In a room if a sound source is nearby, there is little reverberation, whereas if the sound source is far, there is a greater proportion of reverberation. Additionally or alternatively, virtual corridors can be generated, on which the virtual sound source reflects its sound.

A number of options are also possible for changing a stereo quality S of a stereo audio signal. E.g. an angle 160 between a first virtual sound source 152 and a second virtual sound source 154 can be diminished as the mathematical cost c goes up, resulting in a lower stereo quality S . Or the first and second output audio signal o resp. o_2 can be made more similar. Or there can be a hard switch from stereo to mono. Under stereo signal should also be understood multichannel audio, and a corresponding stereo quality S is e.g. the number of channels.

An example of a gradual change between stereo and mono is realized by calculating changed stereo signals L' and R' according to the following equations:

$$\begin{aligned} L' &= (1+a) \frac{L}{2} + (1-a) \frac{R}{2} \\ R' &= (1-a) \frac{L}{2} - (1+a) \frac{R}{2} \end{aligned} \quad [3]$$

By changing the value of a parameter a between 0 and 1, a change between mono and stereo is effected.

The measurement device 312 and second measurement device 352 can be anything, e.g. a clock or a G.P.S. sensor indicating the position of the user 100. In particular it could be a biometric measurement device, such as a pace meter connected to a running shoe, a chest strap or ear-lobe heart rate meter 106, a thermometer, etc. These measuring
5 devices are interesting when used for sports performance measurement. The measurement device 312 could also be incorporated in a professional training apparatus, e.g. a rolling belt for indoors jogging. The style of running –particularly if unhealthy- could also be fed back.

In a game application, a second mathematical cost c_2 can be set by a cost determining means 313, e.g. a random generator. Depending on his luck, the user's 100
10 mathematical cost is set back to the second mathematical cost c_2 and he has to run harder to re-achieve the level of the third mathematical cost c_3 , as determined by a second mathematical cost calculation unit 350 from the second measurement device 352.

Fig. 4 schematically shows an embodiment of the audio feedback system. An audio source 421 delivers an input audio signal i to a conditioning unit 402. The audio source
15 421 can be e.g. a portable audio player or an audio distribution server in a fitness center. A measurement device 412 performs a measurement m , which is converted by a mathematical cost calculation unit 410 to a mathematical cost c , which is also input in the conditioning unit 402. The conditioning unit 402 contains an audio processing means 416, which are arranged to process the input audio signal to obtain an output signal o of a reproduction quality R
20 dependent on the mathematical cost c , which is sent to a sound production means 414, e.g. a pair of headphones or the loudspeakers of a television. The measurement device 412, mathematical cost calculation unit 410, conditioning unit 402, audio source 421, and sound production means 414 can be realized separately or in any combination. E.g., typically an audio reproduction apparatus may contain the conditioning unit 402, audio source 421 and
25 mathematical cost calculation unit 410.

A head tracker may be present, so that the positions of virtual sound sources are corrected for movements of the user's 100 head. Also means may be present –e.g. a microphone- to pick up certain sounds from the environment and mix them with the signal for the sound production device 414 for improved safety.

30 Specification of e.g. the cost function may instead of being done by the user 100 come over a channel –such as e.g. internet- through an interface, from a second person, e.g. a personal trainer. Or the specification may be done at a different time by the user 100, e.g. on his PC. E.g., he can make a training schedule for the whole month, which can be downloaded e.g. wirelessly to the audio reproduction apparatus. Parameters of functions and

functions may even be downloaded from e.g. internet, and e.g. shared between users who want similar training sessions. Specifications made during training and stored in a memory, may also be downloaded through the interface to the computer for further analysis, e.g. training improvement.

5 It should be noted that the above-mentioned embodiments illustrate rather than limit the invention and that those skilled in the art are able to design alternatives, without departing from the scope of the claims. Apart from combinations of elements of the invention as combined in the claims, other combinations of the elements within the scope of the invention as perceived by one skilled in the art are covered by the invention. Any
10 combination of elements can be realized in a single dedicated element. Any reference sign between parentheses in the claim is not intended for limiting the claim. The word “comprising” does not exclude the presence of elements or aspects not listed in a claim. The word “a” or “an” preceding an element does not exclude the presence of a plurality of such elements.

15 The invention can be implemented by means of hardware or by means of software running on a computer, and previously stored on a data carrier or transmitted over a signal transmission system.